Constellation Lessons Learned Executive Summary

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April 2011

Introduction

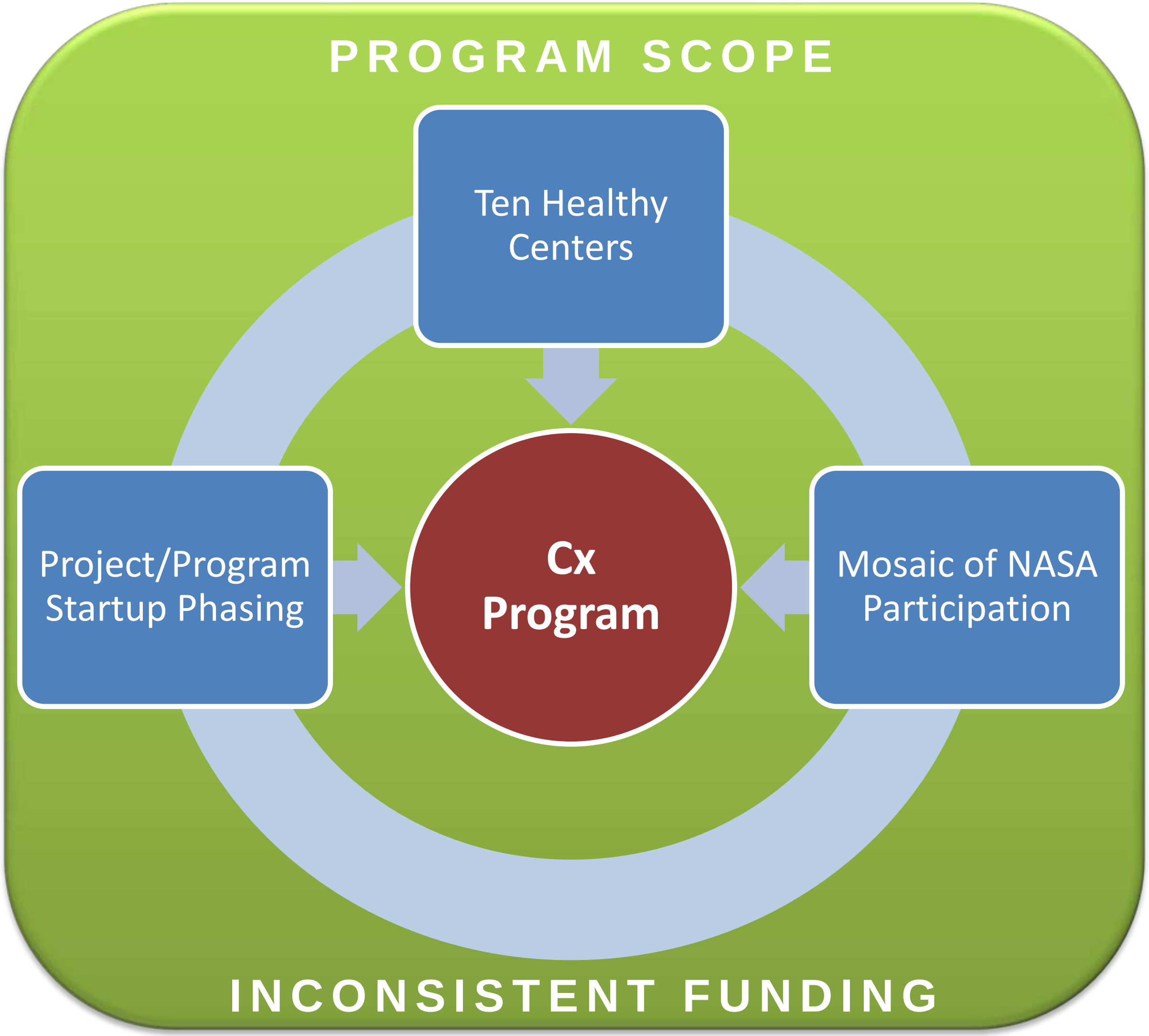
- This package represents the key lessons learned synthesized from hundreds of inputs across the Constellation Program
  - Constellation "Challenge"
  - Individual Program Office activities
  - Project lessons learned activities
  - Ares I-X test flight lessons learned
- The target audience is senior management of new flagship programs or projects which might benefit from the do's and don'ts experienced by the Cx Program
- Includes factors which influenced the Cx Program to provide context for the lessons learned
- Is simply the tip of the iceberg
  - Full reports have been written or are planned, detailing multiple aspects of the program and its accomplishments

Key Lessons Learned

- *Robust vs. optimal planning – the only certainty is that the funding will not match the plan*
- *Schedule creep & the fixed base – the law of diminishing returns*
- *In-house tasks – sustaining the NASA institutional base vs. affordably supporting the Programs – getting from "or" to "and"*
- Flight Tests – learning by doing
- Communications among a far-flung team – interpersonal networks and IT applications can improve bandwidth
- Tailoring of D&C Standards – drinking from a fire hose
- Tailoring process simplification – the law of unexpected consequences
- Risk-Informed Design – risk as a commodity
- *Roles, responsibility, & authority – a non-thermodynamic application of entropy*
- *Decision making – is only as efficient as RRAs are clear & understood*
- *Organization is organic – you'll never get it right, but you can make it better*

NOTE: Italics indicate correlation with Cx SRB Lessons Learned

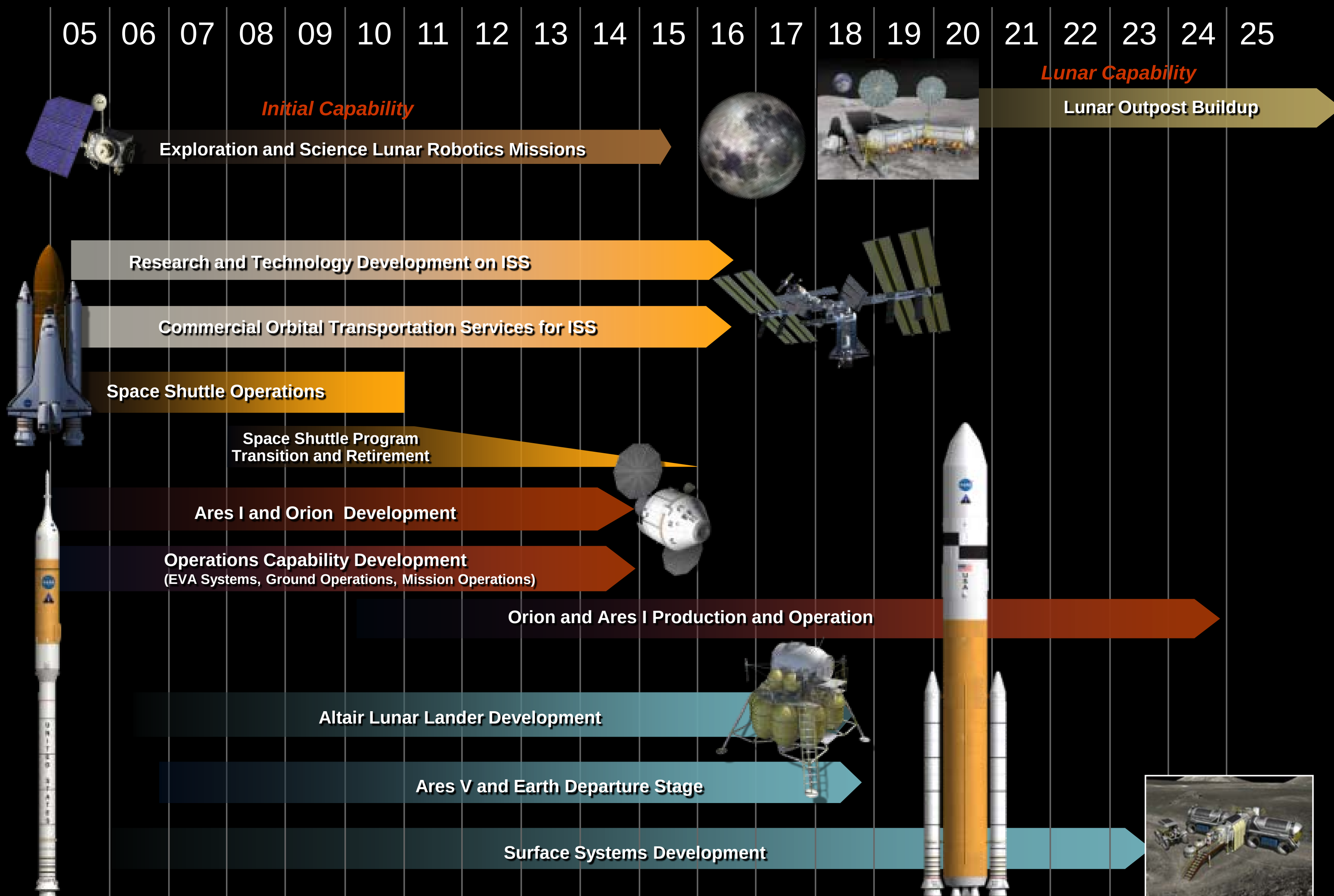
LL Context – Factors influencing Cx



These factors, individually & jointly, influenced the Cx Program in ways both beneficial and detrimental. This provides the context for Cx Lessons Learned.

NASA's Exploration Roadmap

What Is Our Timeline?



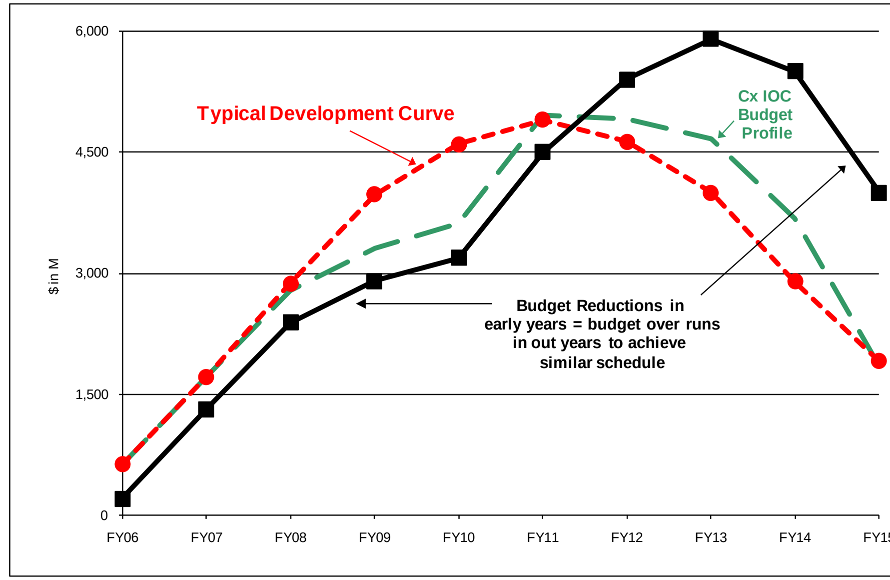
Program Scope – Cx as a multi-decadal undertaking

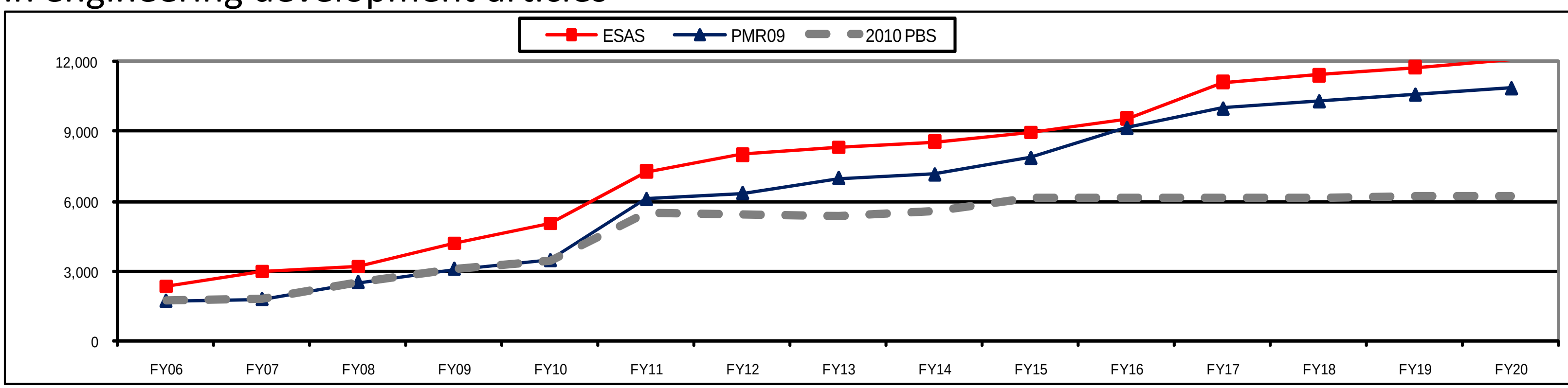
- Program focus on getting beyond LEO drove technical and programmatic decisions that were sub-optimal when viewed from a near-term (e.g. Phase I IOC only) perspective
  - Ares Upper Stage common bulkhead incorporated to provide ascent margin for the block 2 Orion's increased propellant load, and increased near-term risk
  - ESAS configuration to LEO included an Ares I First Stage derived from a four segment booster and SSME Upper Stage Engine
    - Configuration change to five segment First Stage and J-2X engine driven by desire to begin development of components for the heavy lifter (Ares V) needed for beyond-LEO missions

- Long-term, strategic view influenced other Program decisions on organization, application of Agency technical standards (e.g. CEQATR), units of measure (SI), data architecture, etc. that were perplexing when viewed only from an IOC perspective

Inconsistent Funding: Plans vs. Reality

- Through FY10, **10% in real budget cuts**
  - $3.9B worth of content transferred out of Program budget of $17B
  - $1.3B of true budget reductions
- Funding “notch” in FY10 departure from typical development profile
  - Smaller “notch” encountered each year as the FY tended to start with a CR
  - Impaired ability to buy down risks, invest in engineering development articles



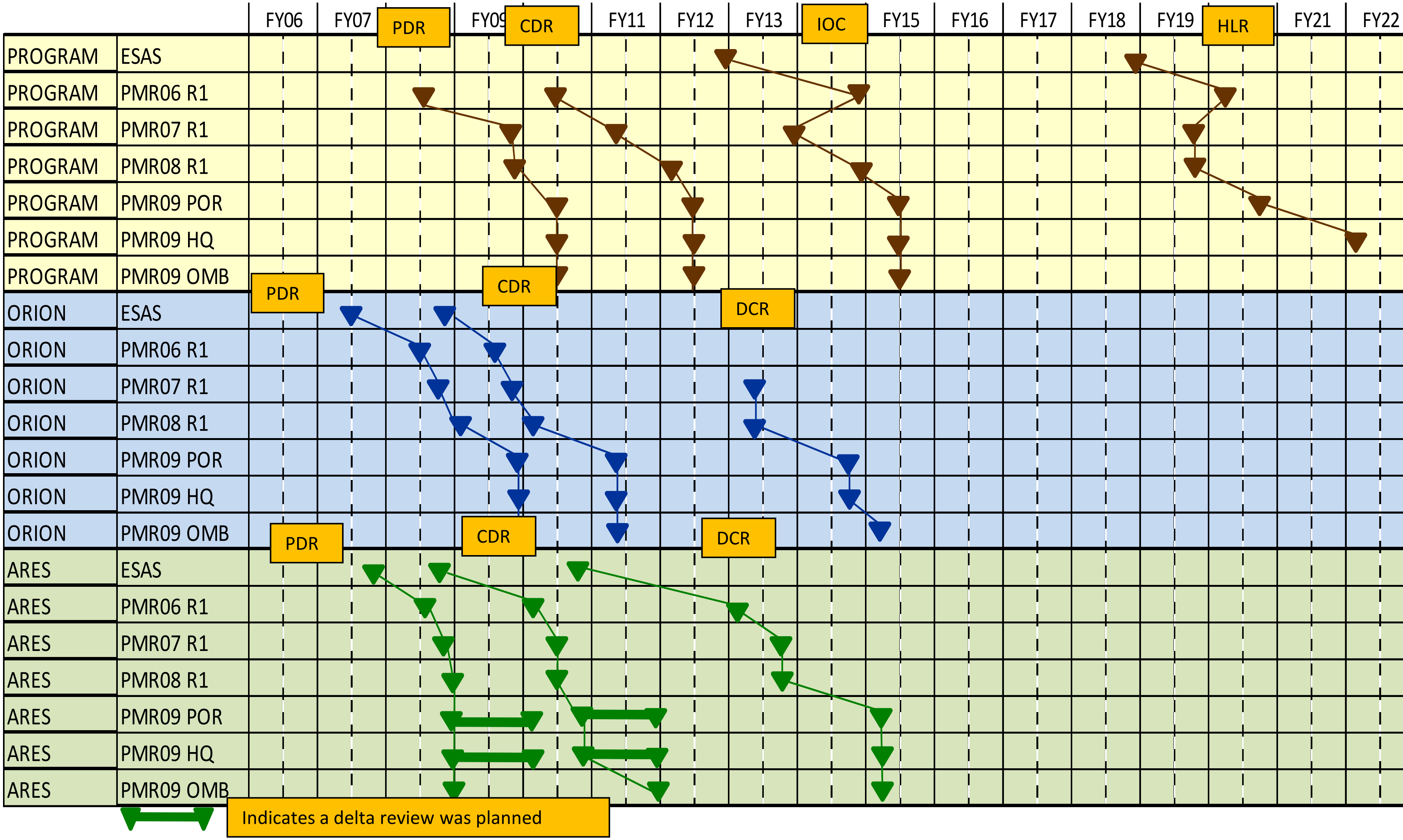


RY$ In M	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	Total
ESAS	2,333	2,976	3,195	4,202	5,034	7,273	7,994	8,324	8,558	8,948	9,547	11,107	11,422	11,744	12,073	114730
PMR09	1707	1779	2514	3085	3454	6085	6346	6991	7145	7856	9145	9983	10294	10582	10854	97820
2010 PBS	1707	1779	2514	3085	3454	5524	5444	5376	5570	6153	6161	6170	6178	6186	6195	71496
PMR09 vs. ESAS Delta	(626)	(1197)	(681)	(1117)	(1580)	(1188)	(1648)	(1333)	(1413)	(1092)	(402)	(1124)	(1128)	(1162)	(1219)	(16910)
Passback vs. ESAS Delta	(626)	(1197)	(681)	(1117)	(1580)	(1749)	(2550)	(2948)	(2988)	(2795)	(3386)	(4937)	(5244)	(5558)	(5878)	(43234)

Inconsistent Funding: The Over-riding Context

- Budget pressure influenced everything – exacerbated all the other factors
  - Efforts to hold schedule without sacrificing content despite funding cuts depleted Cx reserves
- The Contractor's fixed base ramps up proportionately with the contract value, but cuts tend to be absorbed primarily in the variable content – deferring hardware buys, etc.
  - Schedule risk grows as more activities creep onto the critical path
  - Risk mitigation is deferred
- Inadequate reserves or spending flexibility
  - Inability to fund risk mitigations
  - Inability to respond to cash flow disruptions resulting from annual CRs at the beginning of each FY

Funding below Plan: the Consequences



Robust vs. optimal planning – the only certainty is that the funding will not match the plan

- **Lesson Learned**: Reality is that flagship programs (Cx, Webb Space Telescope, etc.) must be robustly planned (e.g. elastic) vs. optimally planned (e.g. inelastic), because absent a national imperative (e.g. race to the moon), funding will not show up as planned.

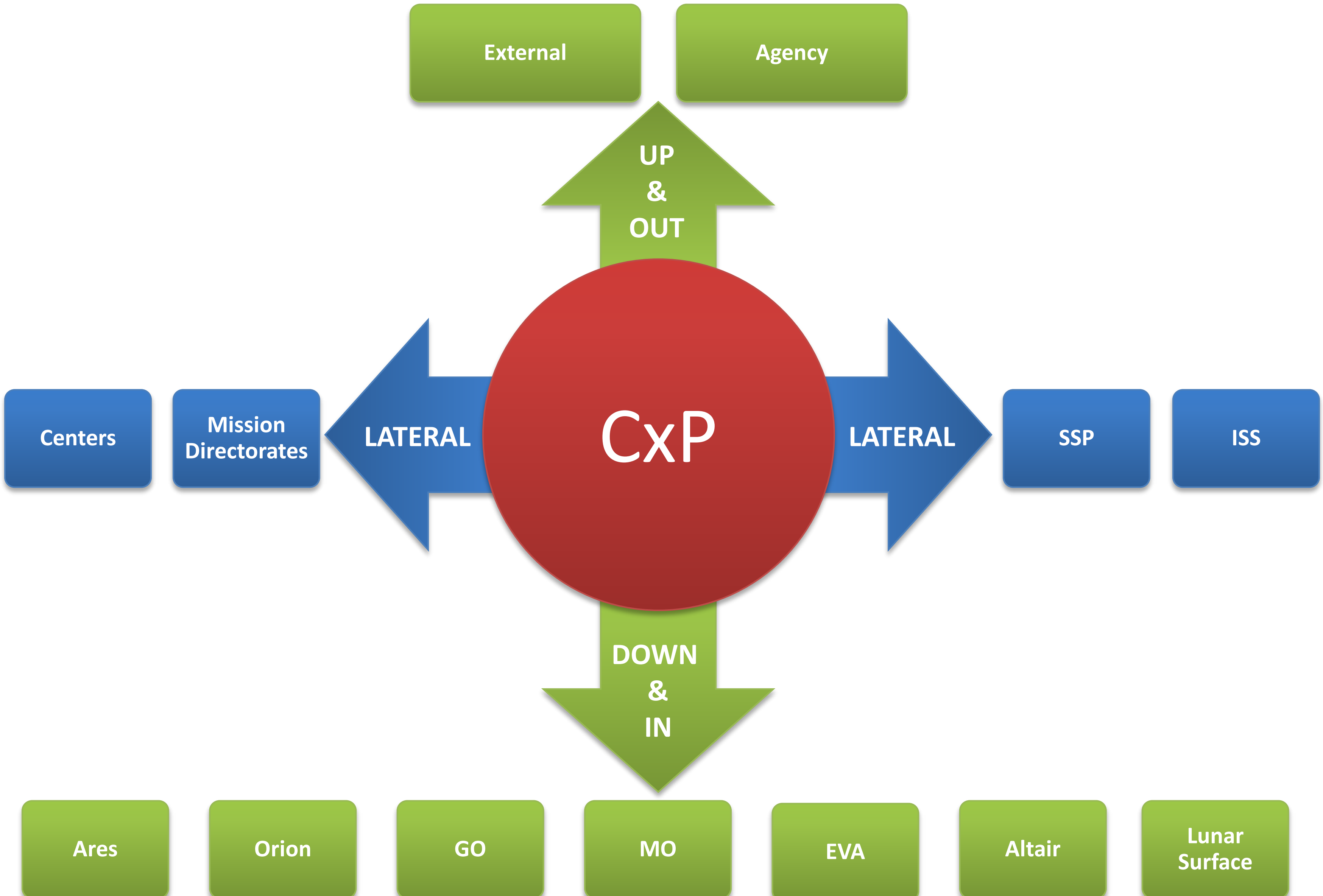
- **Recommendation**: Plan for (1) CRs for first quarter of each year, & (2) strategically, programmatically, & technically decouple the Programs/Projects to the maximum extent, & (3) develop scenario(s) to accommodate a 5-10% funding shortfall in any given year.

Schedule Creep & the Fixed Base – the Law of Diminishing Returns

- **Lesson Learned:** When budgets were not appropriated as planned, schedule was slipped rather than cutting content. Schedule slippage caused Cx to have to cover a larger portion of the NASA HSF transitional fixed base longer, in addition to the fixed base portion of the acquisition itself, leading to a need for still more funding, leading to further schedule slippage – a vicious cycle.

- **Recommendation:** Understand the inherent limitations of schedule slippage to resolve funding shortfalls since fixed cost accrual, both for the NASA Institution and the Contractor(s), erode the buying power of out-year $$. Program content warrants consideration in these instances.

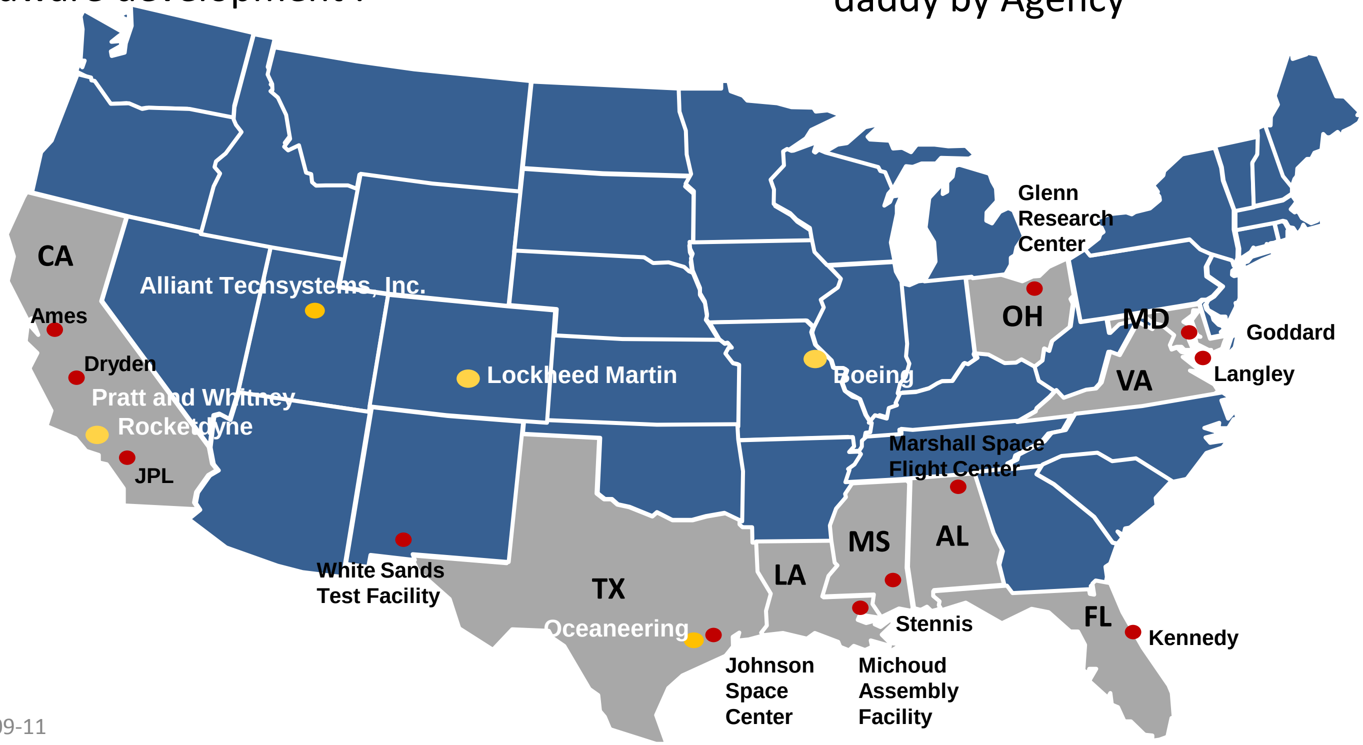
Layers of Engagement



10 Healthy Centers
Cx as an Agency-wide Flagship Program

- **Beneficial Effects**
  - Engagement of non-traditional human spaceflight Centers in Cx allowed Cx to tap into key skills and unique facilities across the Agency.
  - Various Center teams contributed to Cx Program successes in tangible ways – engineering analysis, program integration, & flight hardware development .

- **Detrimental Effects**
  - Different ways of doing business among Centers & contractors led to confused RRA across the Cx Program & convoluted the decision making process.
  - Large team size can mask needed changes to clarify RRA over time
  - Large flagship programs used as a sugar-daddy by Agency



In-house tasks – sustaining the NASA institutional base vs. affordably supporting the Programs – getting from “or” to “and”

- **Lesson Learned:** Tasks performed in-house vs. contracted out are more than just a series of make-buy decisions. Although Cx established a process that emphasized distributing work in logical packages, the competing needs of 10 Healthy Centers, sheer program scope and the Program/Project phasing factor resulted in Center assignments that were not totally coherent, and muddled RRA.

- **Recommendation:** Invest due diligence and look for the win-wins in in-house tasks. In-house tasks can be of value to the Program or Project and solve sustainment challenges for the Institution. Make affordability, institutional benefit, & coherence three strategic considerations in the make-buy decisions for in-house tasks. That is, save the Programs $$ & sustain the Institution while not mucking up RRA too badly – make sure the gain is worth the pain.

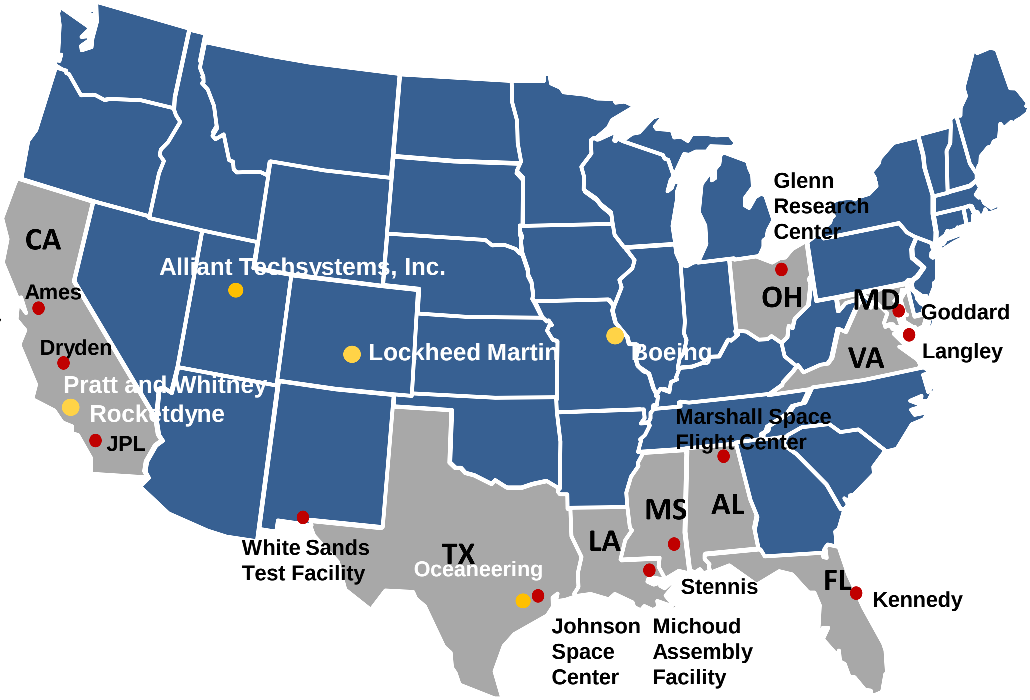
Flight Tests – Learning by Doing

- **Lesson Learned**: Many programmatic & technical methodologies required for efficient execution of Ares I-X & Pad Abort-1 were generically applicable to both flight tests and revealed opportunities to improve the Cx mainline effort.
  - Balancing of flight test objectives against resources
  - Selection and tailoring of applicable technical standards
  - Degree of relaxation of rigor consistent with uncrewed flight test context
  - Management of margin stackup/accumulation between disciplines
  - Establishing the test instrument suite specification
  - Demonstration of processes required during routine operations
  - Anchoring and validation of engineering models

- **Recommendation**: Resist the temptation to rely on ground test due to its apparent relative economy compared to flight test. A well-planned flight test provides significant return-on-investment, largely in dimensions other than just the test data.

Communications among a far-flung team – interpersonal networks and IT applications can improve bandwidth

- **Lesson Learned:** A network of Project & Program Integration Deputies fostered programmatic communication & issue resolution. "Community of Practice" technical networks fostered technical communication & issue resolution. Information technology (telecon, Webex, LifeSize, ICE/Windchill, etc.) facilitated effective performance for geographically dispersed Cx teams, although no substitute for F2F discussions.
- **Recommendation:** Flagship, geographically disperse Programs can benefit from interpersonal networks to enable cross-organizational communications. Likewise, affordable state-of-the-art IT tools facilitate communications across time & space, and should be put in place early & to a broad extent.



Mosaic of NASA Participation – the many faces of NASA in a flagship acquisition

- **Beneficial Effects**
  - Access to NASA knowledge base, needed skills & infrastructure
    - Acquisition roles (e.g. Program/Project Office)
    - Technical Issue resolution
    - GFE (in particular instances)
    - Unique facilities (i.e. test stands, chambers, etc.)

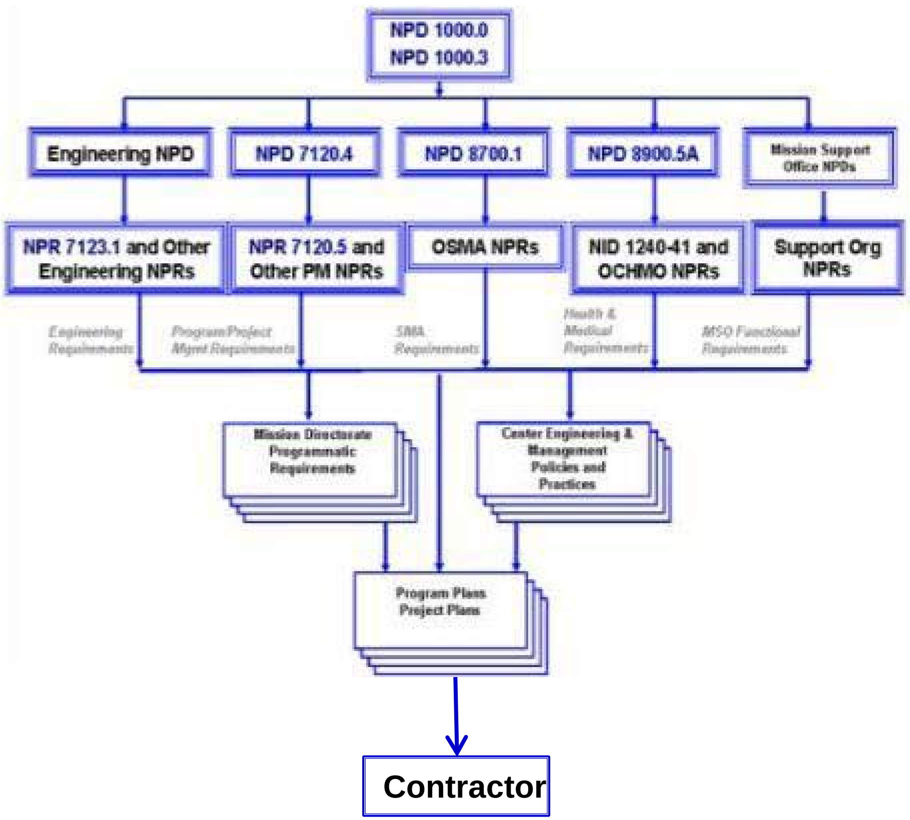
- **Detrimental Effects**
  - Adherence to NPDs and D&C Standards drives contractors through burdensome "meets or exceeds" process
  - NASA roles tend to be fungible to cover gaps in institutional & workforce coverage Center to Center & project to project; lack of coherence across the Agency complicates Program management
    - Excessive usage of personnel in "insight" role burdens contractors
  - Technical authority vs. Program/Project authority confounds the decision making process

Tailoring of D&C Standards – drinking from a fire hose

Lesson Learned: The sheer quantity of D&C standard imbedded requirements to be tailored is an impediment to any effective process.

Recommendation: Major Aerospace Contractors build systems for multiple Government customers including DoD, NSA, & NASA among others, and not all Agencies require detailed standards because suppliers have certified internal processes & procedures that meet National Standards. NASA should establish an experienced team to audit supplier internal processes at the document level with a process that does not burden the Contractor with defending each individual requirement's adequacy.

Relevant Activity: This topic is the subject of Affordability/Innovation Discussions with Chief Engineers, Health & Medical, and S&MA Leadership, which tasked a sub-team to describe a process and timeline for transforming approach to TA requirements and standards. ***Recommend this initiative establish clear criteria for mandatory ("shall") requirements and revalidate the Agency's current requirement base with the goal of significantly reducing the number of requirements levied by the Agency.***



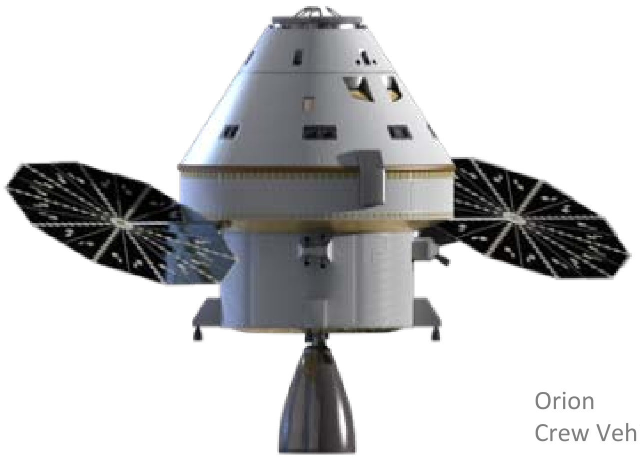
Tailoring process simplification – the law of unexpected consequences

Lesson Learned: A simplification in the tailoring process for various NASA NPDs and D&C Standards was to use the waiver & deviation process. Well understood, analogous process – easy, right? Problem was that waivers & deviations carry a very negative connotation in the HSF culture, and actually confounded the tailoring process rather than streamlining it.

Recommendation: Tailoring is a good thing, and should not carry the stigma of some form of shortcoming that is rightly associated with deviations & waivers. Alter the tailoring process to remedy this negative implication.

Risk-Informed Design – risk as a commodity

Altair
Lunar Lander

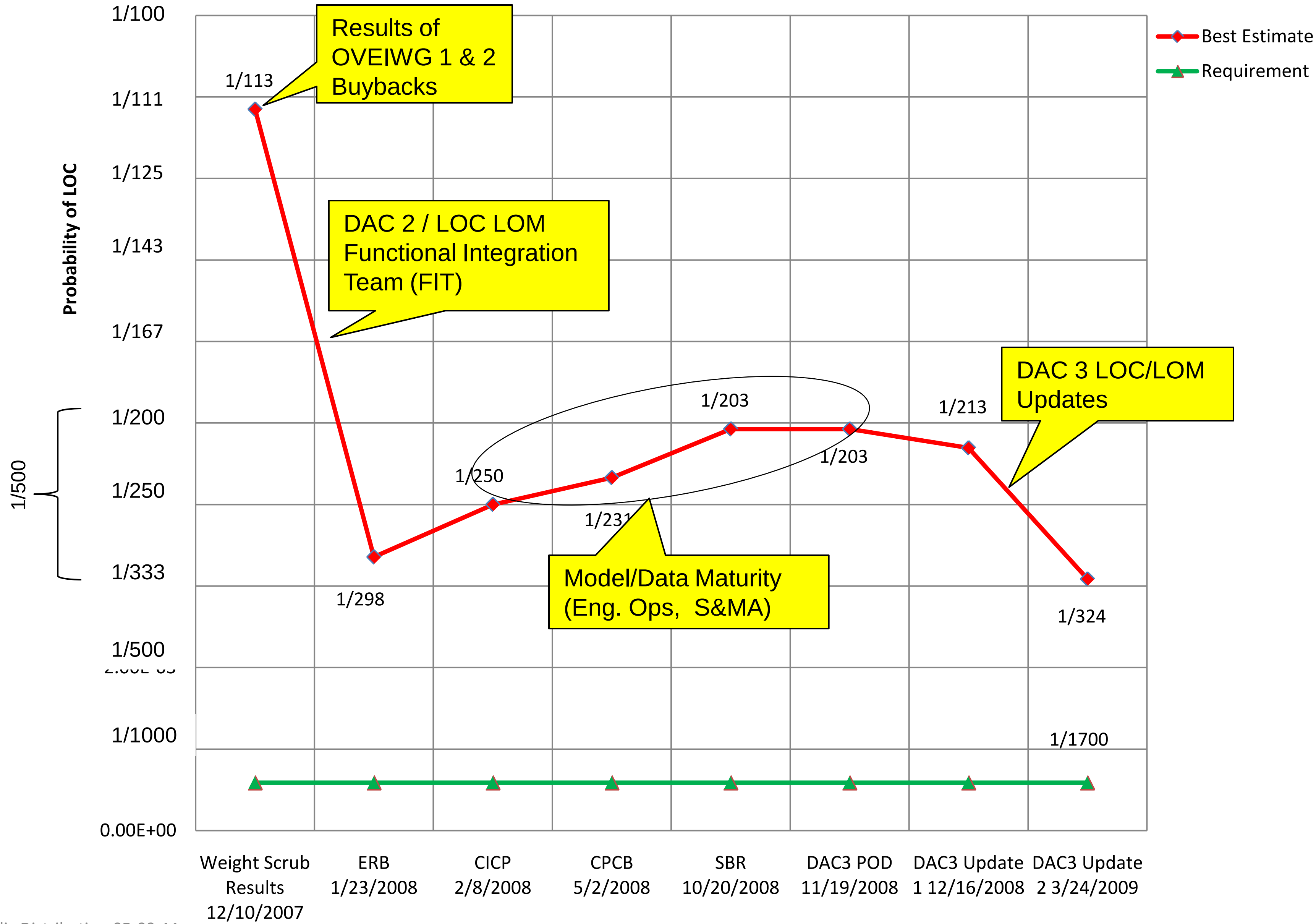


Orion
Crew Vehicle

- **Lesson Learned:** Both Orion and the Lunar Lander initially struggled with meeting their mass constraints. Subsequently, those teams employed a design process that zero-based non-mission driven requirements, and then conducted risk-based trades to optimize vehicle reliability and safety. The result was a breakthrough, yielding a design solution that closed and was more reliable/safe than the initial approach that had “followed the rules.”

- **Recommendation:** A rule-based approach can remove accountability for understanding the implications of design choices. Employ risk-informed design methodology up-front to keep the focus on mission success versus following “design rules”.

ISS LOC Trend



Projects Established Before Cx Program

- Beneficial Effects
  - Early focus on projects allowed Cx to get out of the gate quickly.
  - Projects had to function absent formal integration early on, leading to an eventual Program Integration effort that was very lean by historical norms.

- Detrimental Effects
  - SI Unit policy, Data Architecture, Facilities Management, & other integration strategies that were in a collective self-interest for the Cx Program were extraordinarily difficult to implement due to the cost of various contract changes.
  - Proliferation of boards & panels, duplicate yet subtlety different between projects, and then compounded upon Program stand-up, confounded the decision-making process.
  - Integrated analyses performed by Program uncovered technical issues (induced environments) that could have been caught earlier but for phasing.

Roles, responsibility, & authority – a non-thermodynamic application of entropy

Lesson Learned: RRA and decision-making were detrimentally effected by all three factors influencing Cx. This remained a challenge throughout the life of Cx and received diligent attention. Periodic 4D surveys indicated improvement over time in response to corrective measures.

Recommendation: There is no cookbook, no checklist solution for crisp & clear RRA in an Agency-wide, flagship program like Cx; likewise for a decision-making process that enables timely decisions at the appropriate levels to balance strategic vs. tactical viewpoints, with clearly delineated accountability. Rather, the lesson learned is to be diligent from the start & constantly pursue improvements in crispness and clarity.

A couple of instances of clarifying RRA…

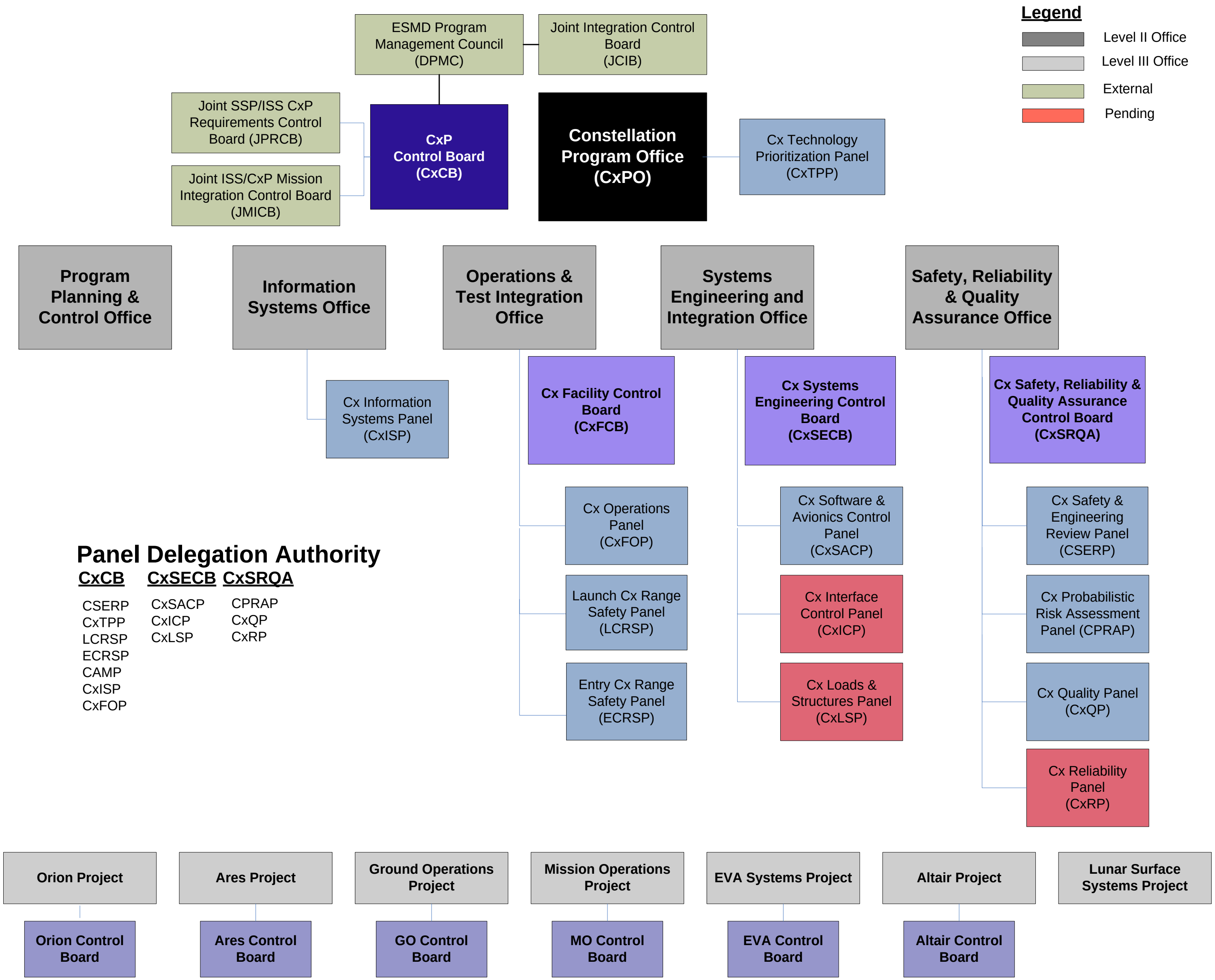
- Sometimes we had roles combined that needed to be separated, and sometimes we had roles separated that needed to be combined
  - The Cx Program struggled to establish an Integrated Master Schedule (IMS). When the role of IMS development was separated from IMS assessment, things quickly fell into place.
    - **Recommendation:** The IMS must be developed by the product/task providers & the integrators as an integration tool with that focus, not as a pull function from the assessors to an assessment tool.
  - Confusion existed on how the risk management process should be applied for cost threats. The risk management process was run by SMA, & the budget threat process by PP&C, leading to confusion & frustration.
    - **Recommendation:** Include Chief Engineers, Chief Safety Officers, and Resource Managers in the risk management process. Each has a specific role that should be defined in the Risk Management Plan. Caution is warranted when addressing issues that are driven by budget shortfalls. Review these issues in the project's planning/replanning arena before they are categorized as risks. ***Finally, have budgets for risk mitigation because without funds, risks are automatically accepted and trend to issues.***

Decision making – is only as efficient as RRAs are clear & understood

- **Lesson Learned:** RRA and decision-making were detrimentally effected by all three factors influencing Cx. The Cx Program was spread across multiple Centers, multiple projects, & multiple integration entities, each with their own ways of vetting technical recommendations/decisions, sometimes leading to inconsistent management direction. Further, when an issue arose, there was often confusion about the appropriate "entry-point" into the decision making process. As with RAA, this remained a challenge throughout the life of Cx and received diligent attention, and periodic 4D surveys indicated improvement over time in response to corrective measures.

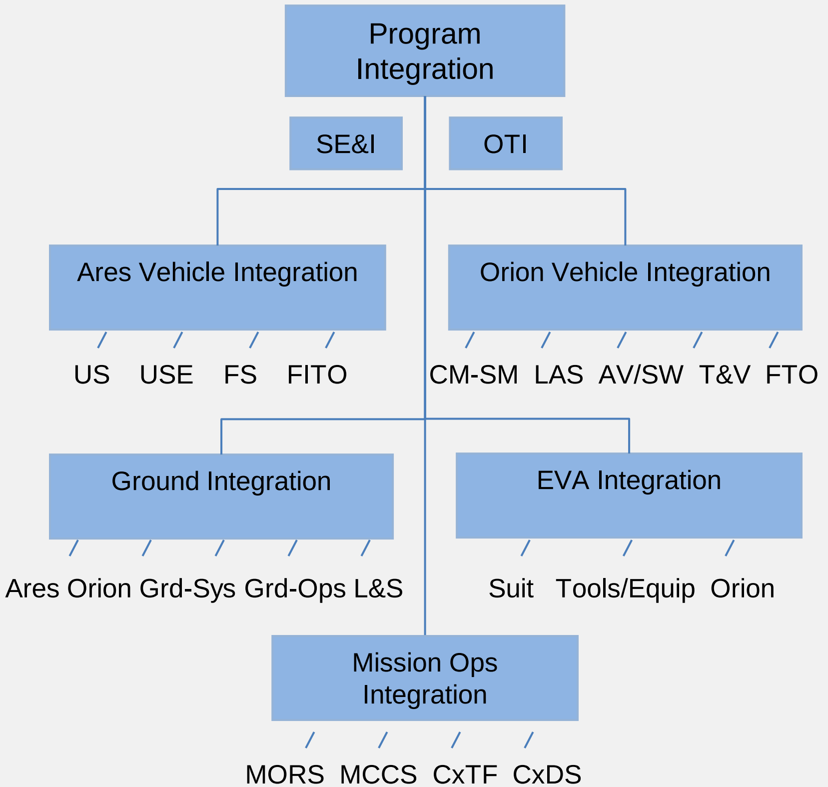
- **Recommendation:** Invest the time & energy to define a comprehensive decision process that includes the Program, Technical Authority, Center, and Contractor decision processes. If you don't take the time to understand this up front, don't worry – it will reveal itself one impediment at a time.

Decision making – is only as efficient as RRAs are clear & understood

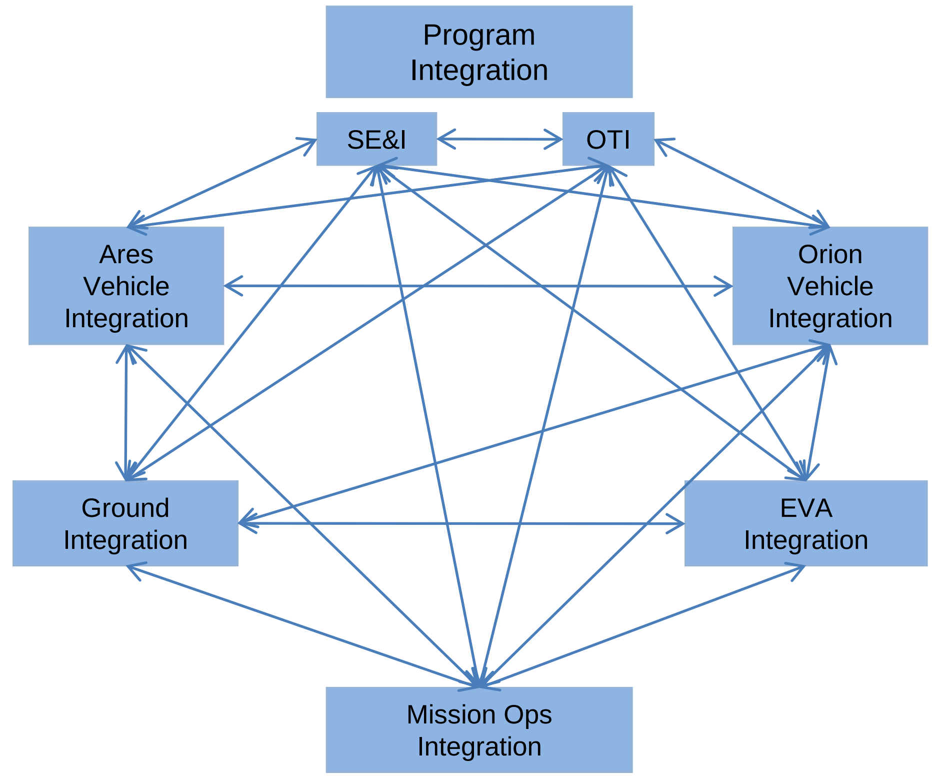


Decision making – is only as efficient as RRAs are clear & understood

What you think is working like this:



Is really working like this:



* Multiply by # of Boards, Panels, Working Groups, Discipline Groups, Stakeholders, etc

Organization is organic – you'll never get it right, but you can make it better

Lesson Learned: The organization for a flagship program is organic and must adapt over time to the nature of the work. Size/scale & hierarchy can mask this. Cx was about a year slow in changing SE&I from a requirements focus to a design integration focus in the wake of SDR completion. However, that lesson was learned & not repeated; Orion & Ares implemented reorg's in the wake of PDR completions, making changes needed to progress to CDR, and Cx was in the process of a post-PDR reorg when proposed for cancellation.

Recommendation: Revisit the organization at key milestone reviews to address the changing nature of the work ahead to achieve the next key milestone. This revisit should come in the form of a program plan update portion of milestone review up-brief to Agency management, since Agency management must be enlisted to mitigate social impacts across Centers due to ebb and flow of assigned work.

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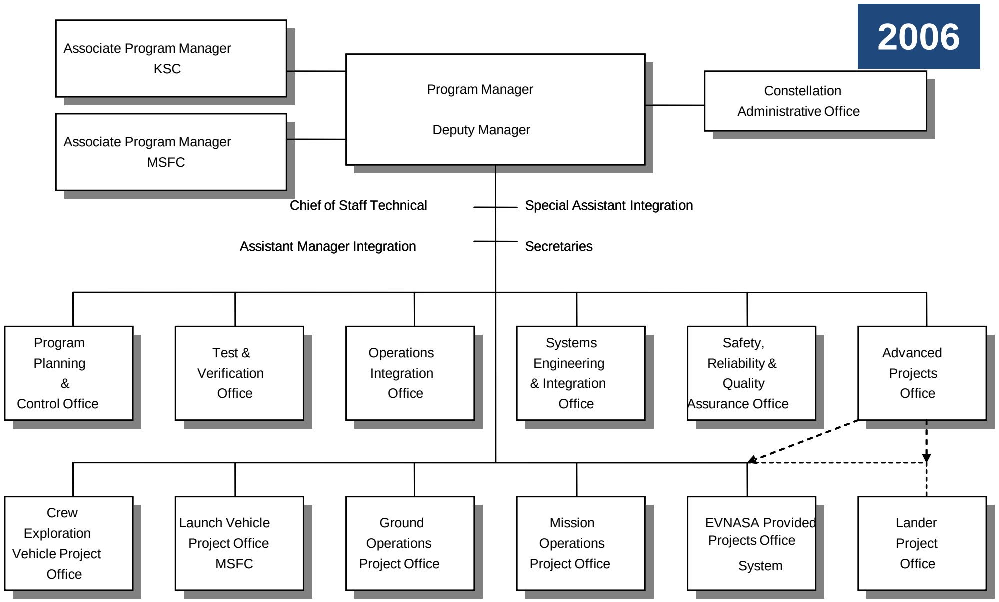

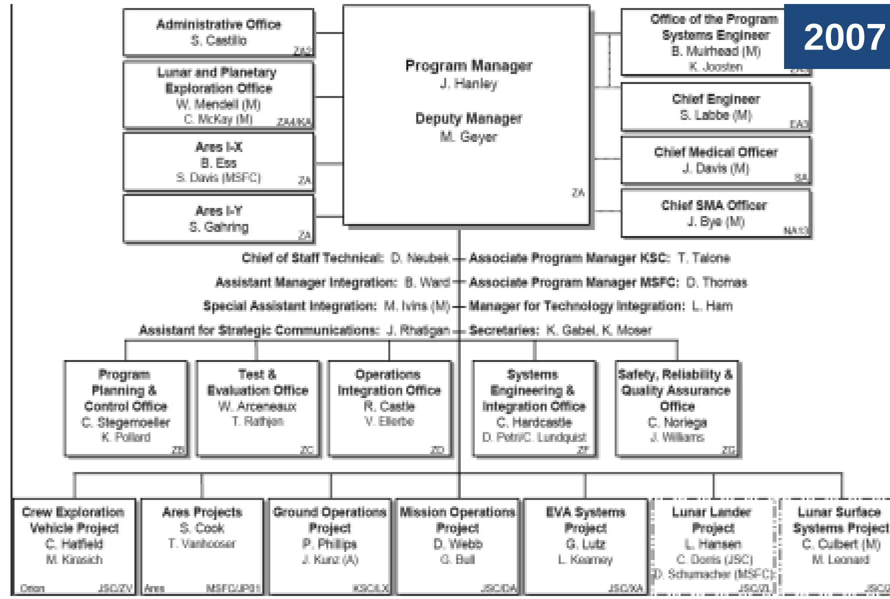

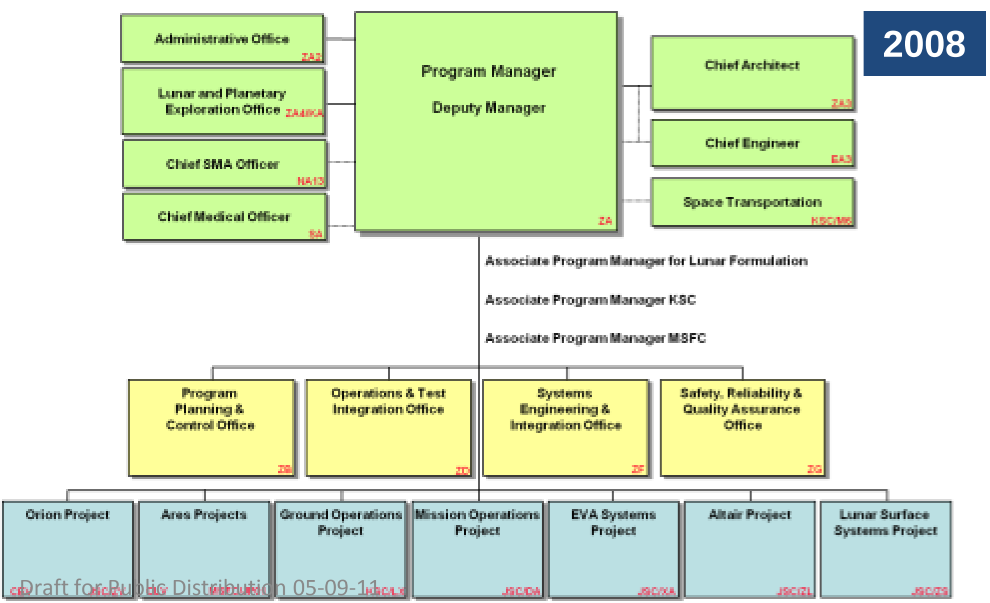

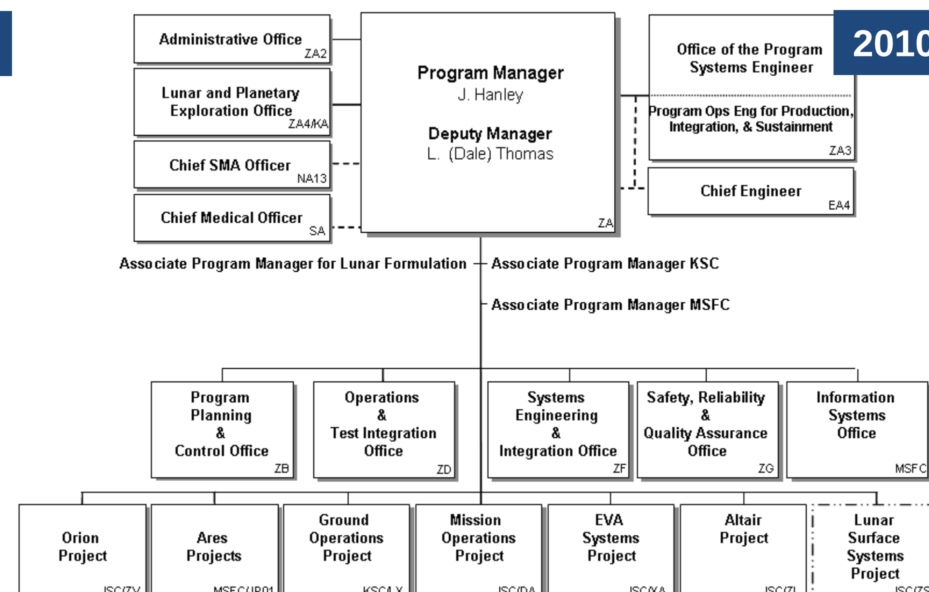

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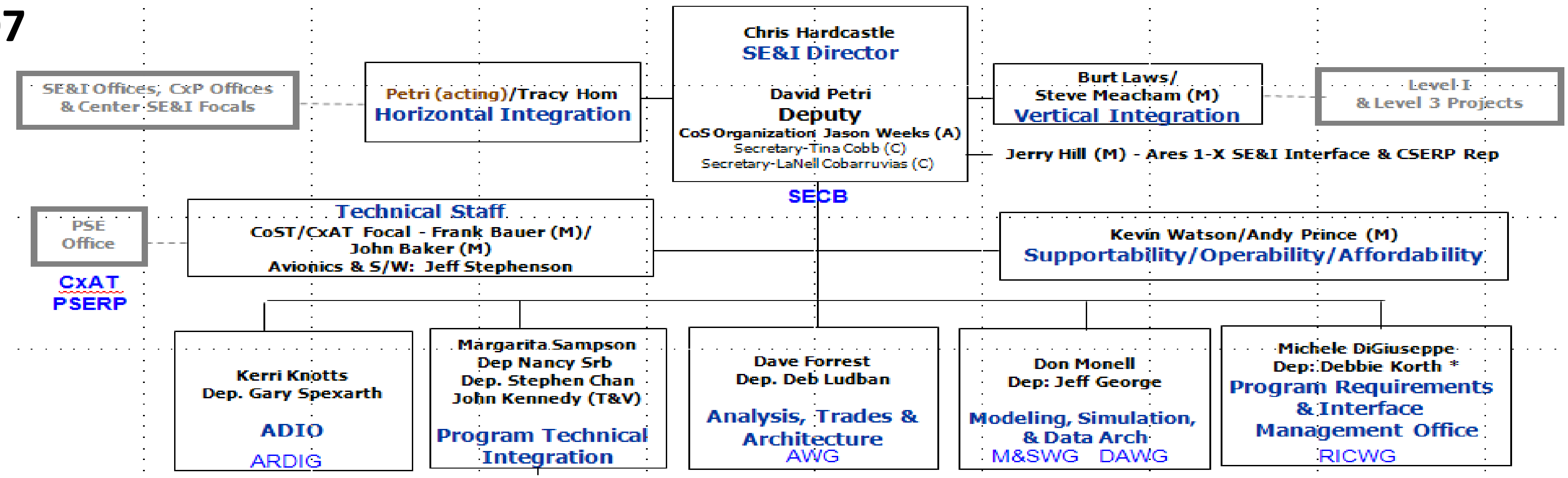
Cx Lessons Learned Activities

- Program level
  - Cx Challenge
  - Final LL report
  - Individual office efforts
  - Cx LL wiki
  - KBRs
  - Multiple conference papers
- Ares I-X
  - Wiki site
  - Knowledge Capture Report
  - KBRs including video interviews
  - Technical reports
- Ares
  - Ares I Final LL report
  - KBRs
- Orion
  - KBRs
  - PA-1 Final Report
- Ground Ops
  - 357 approved LLs being entered into the NEN LLDB
  - KBRs
- Mission Ops
  - PM Challenge papers
- Altair
  - Formal LL report
  - Engine KBR

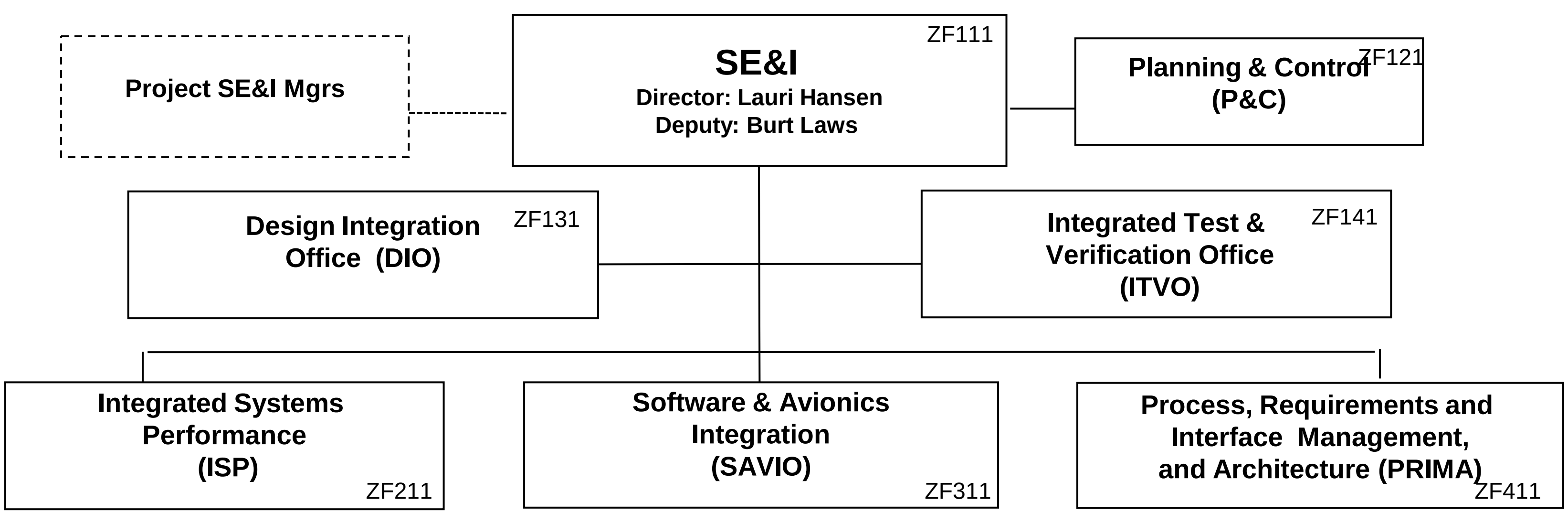
Back-Up

SE&I Org 2007 vs 2010

2007

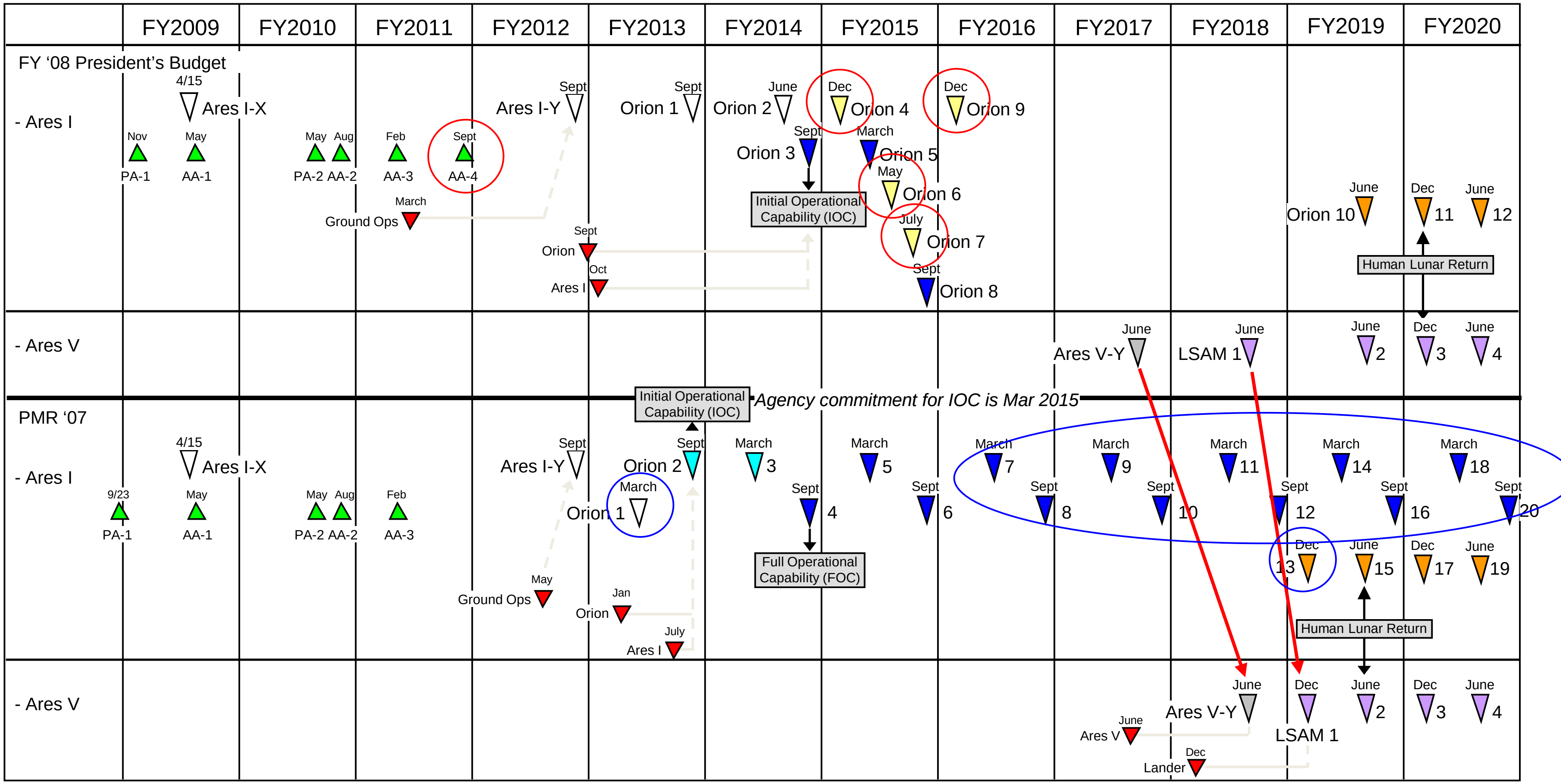


2010



Overview - Manifest

FY08 President's Budget Baseline vs. PMR '07



= ISS Crew Flight

= ISS Uncrewed Pressurized Cargo Flight

= Lunar Sortie Cooperative Crew Flight

= CEV LAS Pad Abort (PA) or Ascent Abort (AA) Test

= Ares I / Orion Test Flight

= Ares I / Orion Crewed Test Flight

= Ares V Test Flight

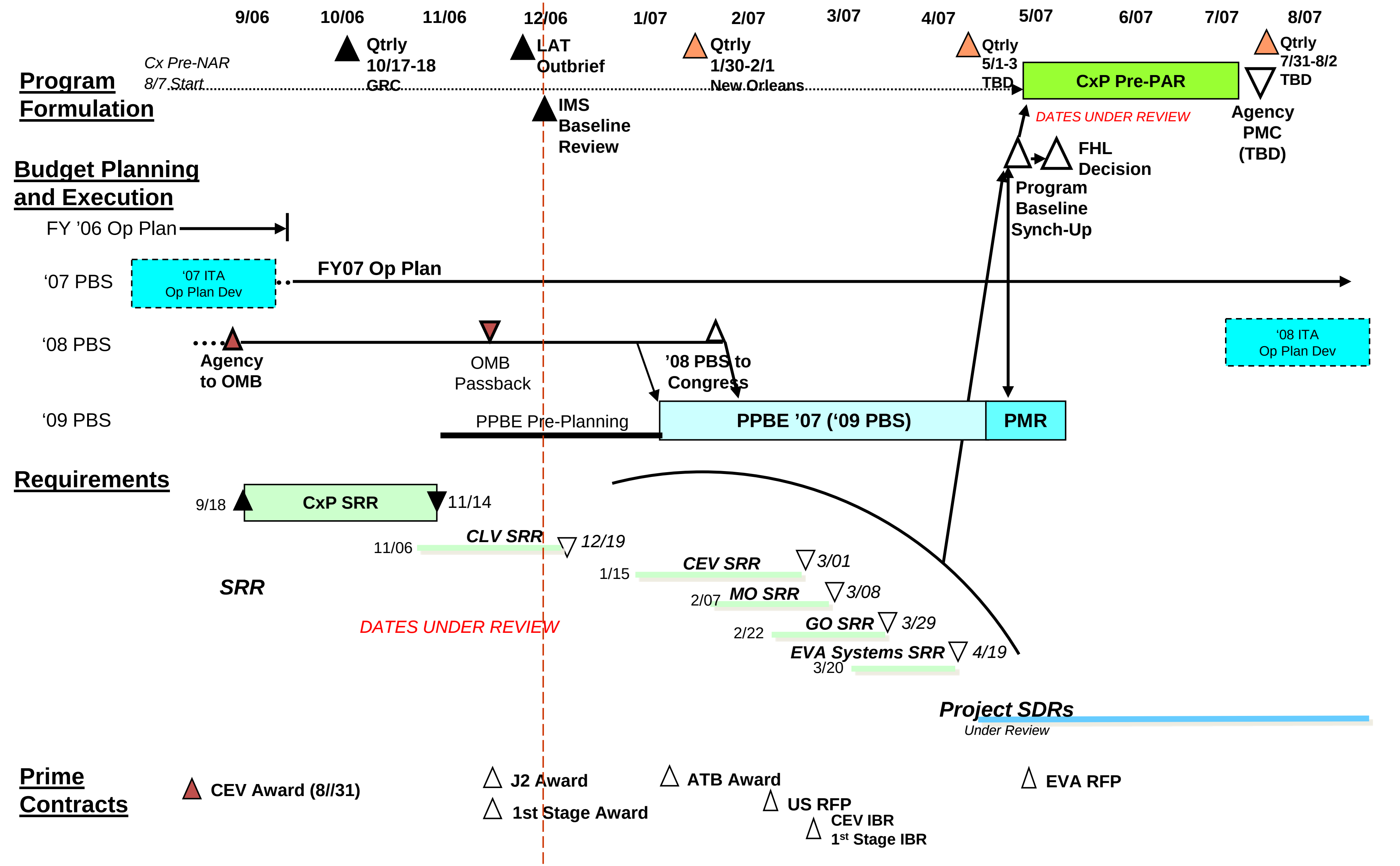
= Ares V / LSAM Lunar Sortie Flight

= Project DDT&E Complete / Schedule Reserve

Deleted Flights and Tests

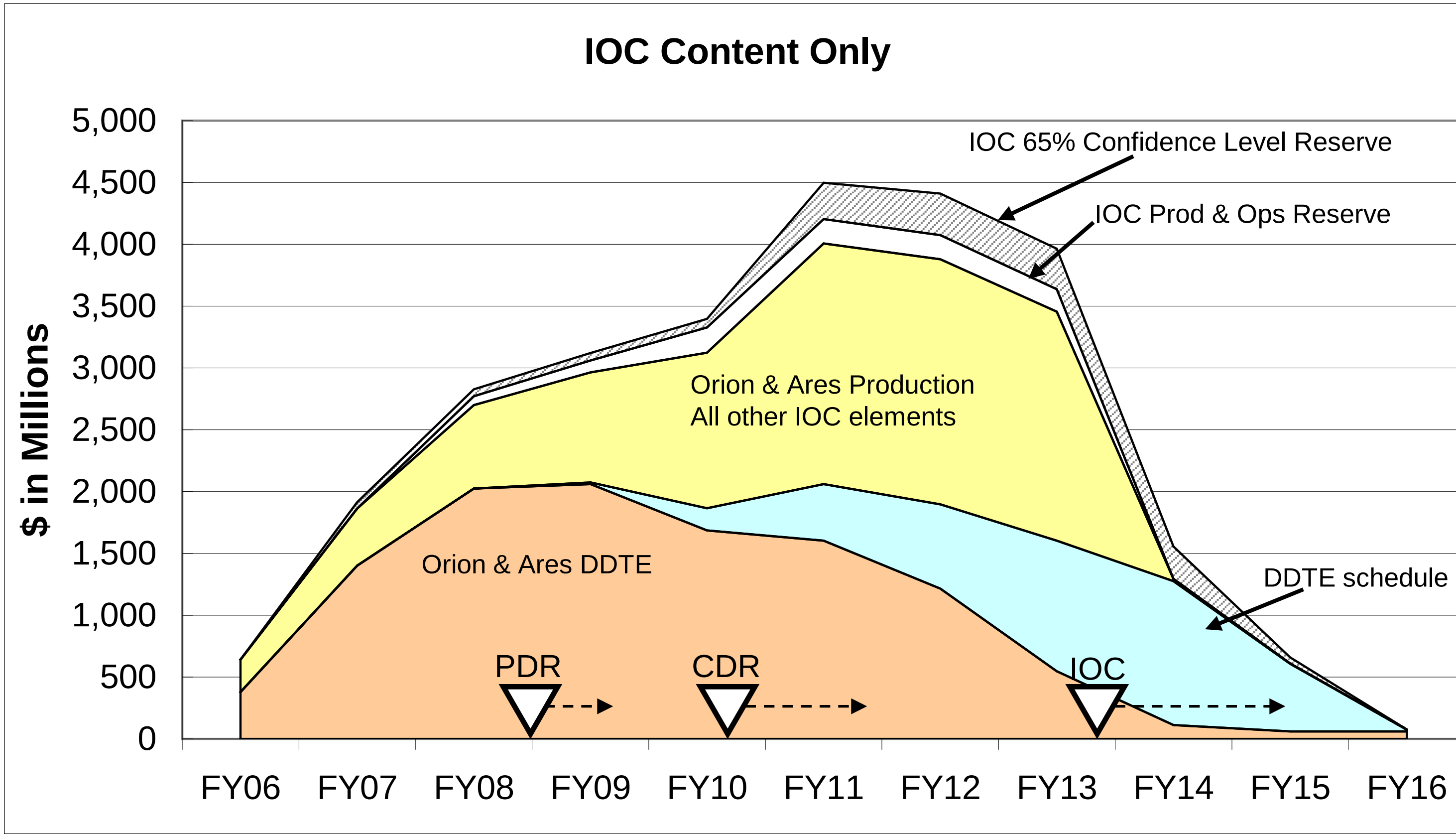
Added Flights and Tests

Constellation Program Integration Roadmap – 12 months



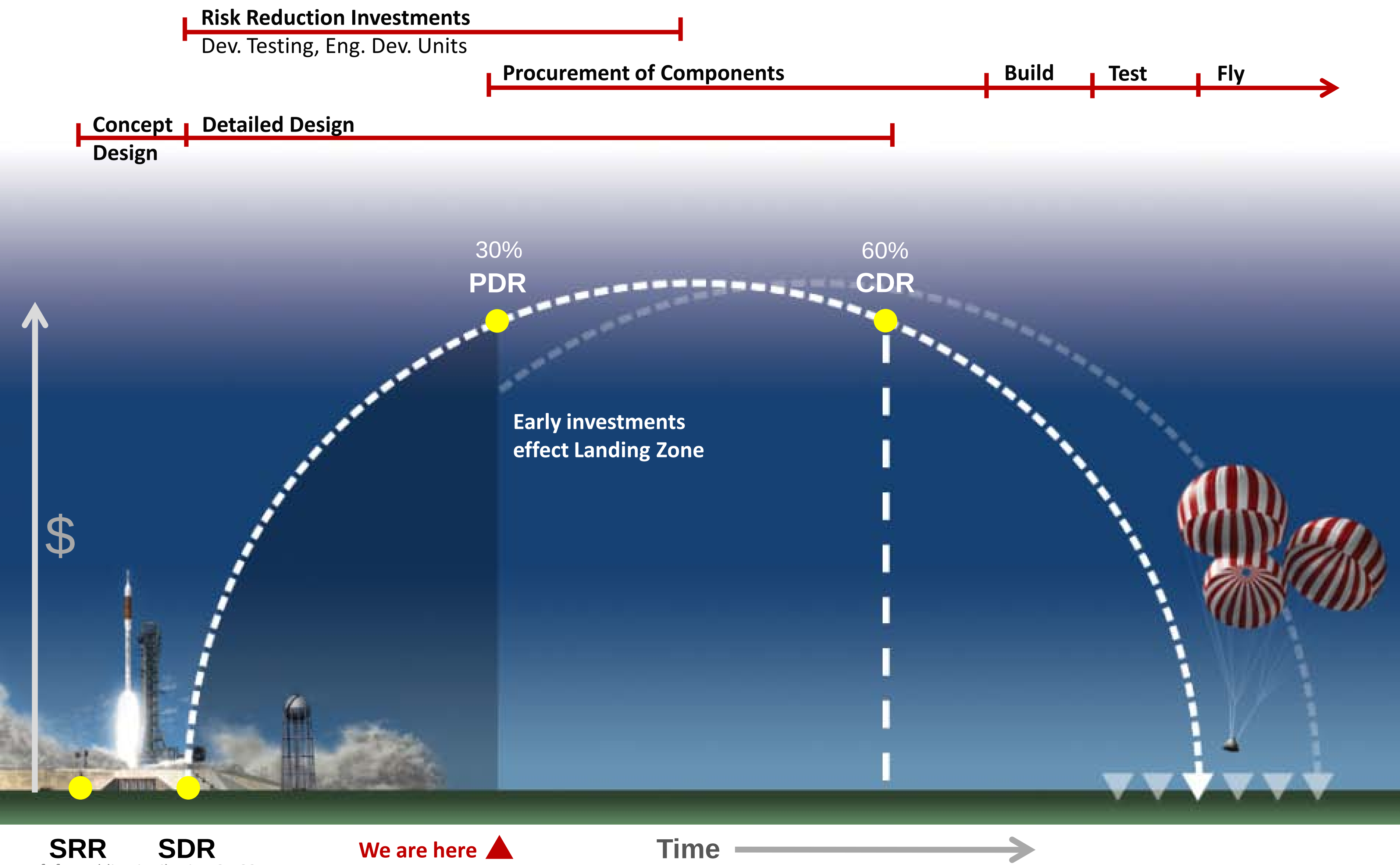
Program Manager's Recommend

IOC Reserve Strategy ($M Cost)



	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	Total
Total IOC Cost	641	1,915	2,827	3,122	3,396	4,497	4,410	3,964	1,556	659	77	27,064
Orion & Ares DDTE	378	1,401	2,024	2,061	1,687	1,603	1,215	547	111	60	60	11,147
DDTE 2 years sched Reserve				14	179	458	682	1,056	1,164	547	15	4,115
IOC Prod & Ops Proj Content	263	463	676	889	1,258	1,945	1,982	1,852	18	2	2	9,350
IOC Prod & Ops Reserve	0	0	72	96	203	197	194	181	1	0	0	944
IOC 65% Confid Level Reserve		51	55	62	69	294	337	328	262	50		1,508
Cum Reserve as % Proj Budgets					7.20%						32.0%	

Program "Trajectory"



Constellation Center Summary

4-26-06

ARC Task Distribution

- **Crew Exploration Vehicle (CEV)**
  - **LEAD** Thermal Protection System (TPS) Advanced Development Project
  - Aero/Aero-Thermal database development team
  - Flight Software and CEV Guidance Navigation and Control support
- **Crew Launch Vehicle (CLV)**
  - Expertise in Integrated Systems Health Monitoring (ISHM) including design and development phase health monitoring requirements analysis, CLV element fault detection algorithms development, and DDT&E and V&V tools development
  - Support reliability assessment with Monte Carlo simulations
  - Ascent Abort CFD Blast Analysis
- **Mission Operations**
  - Exploration tools for flight controllers
  - Development of new applications to future requirements for the Constellation training program
  - Support DDT&E of multi-Center Command &Control systems, human-machine interaction requirements, mission control software development, project planning and management software systems, and documentation systems
- **Level II**
  - PP&C - Data systems support
  - SR&QA - **Development** of PRACA and SMA Information Systems
  - SE&I - Support to Human Factors and Human Rating, Flight Performance, Thermal & ECLS, C3I, EVA and Ground/Mission OPS Systems Integration Groups (SIGs)
  - T&V - Support to Human Factors and Human Rating, Integrated Thermal/ECLS, C3I T&V, and Avionics SW T&V SIGs
  - APO -Support architecture refinement and conceptual design of future elements

DFRC Task Distribution

- **Crew Exploration Vehicle (CEV)**
  - **Lead** for Abort Flight Test Integration and operations
  - Abort Test Booster (ATB) procurement
  - Flight Test Article (FTA) and ATB integration
  - FTA design, assembly, integration and test
  - Independent Analysis and Oversight of prime contractors FTAs
- **Ground Operations**
  - Support preliminary definition and planning for CEV launch abort systems tests, drop tests, landing and recovery tests, flight re-entry and landing profiles, range safety requirements and integration
- **Level II**
  - SE&I – Support to C3I Systems Integration Group (SIG)
  - T&V - Flight Test Planning Support

GRC Task Distribution

- **Crew Exploration Vehicle (CEV)**
  - **Lead** for Service Module (SM) and Spacecraft Adapter (SA) Integration
    - CEV Prime Contractor Oversight and Independent Analysis
  - Flight Test Article and pathfinder production for SM and SA
  - Integration Analysis and SE&I Support
- **Crew Launch Vehicle (CLV)**
  - **Lead** responsibilities for Upper Stage
    - Design and develop the Thrust Vector Control (TVC) subsystem
    - Design and develop the Electrical Power and Power Distribution System
    - Developmental Flight Instrumentation (DFI) Package
    - Leak detection Sensors Development
    - Purge System
    - Hazardous Gas Detection system
  - **Lead** for Upper Stage module development for Advance Development Flight Test-0 (ADFT-0)
  - Upper Stage SE&I support
  - J-2X thermal/vacuum testing at Plum Brook B-2 facility
  - Vehicle Integrated Design Analysis support
- **Level II**
  - SR&QA - **Lead** for FMEA Integration and program trends analysis; Support for document maintenance, program trending, integrated hazards analysis, and quality audits. Represent SR&QA at assigned Systems Integration Groups (SIGs)
  - SE&I Integrated Power SIG **co-lead**, **Book manager** for several SRR IRDs, support to Analysis & Trades and Process & Tools Office, and support to Flight Performance, Thermal & ECLS, C3I and EVA SIGs
  - T&V - **Lead** for Electrical Power Test Bed definition/architecture; **T&V lead** for Power SIG; Support to Avionics Test Architecture
  - APO - Support architecture refinement and conceptual design of future elements

GSFC Task Distribution

- **CEV**
  - Communication and Tracking Support
  - Mechanisms support
- **Level II**
  - SR&QA - Level II Software Safety and Assurance; Represent SR&QA at assigned Systems Integration Groups (SIGs)
  - SE&I **-** Navigation SIG **co-lead**; Software and Avionics SIG **co-lead**, support to Flight Performance and C3I SIGs
  - T&V - C3I T&V SIG **lead**, Navigation & Tracking T&V SIG **lead**, **Book Manager** for Software V&V Plan; Support to Avionics SW T&V SIG, RF link testing, and Interface verification requirements
  - APO - Support architecture refinement and conceptual design of future elements

JPL Task Distribution

- **CEV**
  - Support to TPS Advanced Development Project
- **Mission Ops**
  - **Lead** for a Systems Engineering Process for OPS Development (SEPOD) - multi-center activity to lay out a road-map for the systems engineering processes related to ops development/preparation for the new program.
- **Level II**
  - SR&QA - Support for integrated hazards analysis and probabilistic risk assessment; Represent SR&QA at assigned Systems Integration Groups (SIGs)
  - SE&I Software and Avionics SIG **co-lead**; support to Requirements, Analysis & Trades, and Process & Tools Offices; support to Nav & Track, Power, C3I, Human Factors and Ground/Mission OPS SIGs
  - T&V - Support to Master Verification Plan, Cx Environmental Qualification and Acceptance Test Requirements (CEQATR), and Master T&V; Support to C3I T&V and Avionics SW T&V SIGs
  - APO - Support architecture refinement and conceptual design of future elements

JSC Task Distribution

- **Constellation Program**
  - **Program Management**
  - Manage and integrate Crew Exploration Vehicle (CEV), Crew launch Vehicle(CLV)/Heavy Lift Launch Vehicle (HLLV), Launch Systems, Mission Systems, Exploration Communication and Navigation Systems, and Extra Vehicular Activity (EVA) Projects
- **CEV**
  - **Overall Project Management and Integration– CEV Prime Contract Management**
  - **Lead** for Crew Module and Vehicle Integration
    - CEV prime contractor oversight and independent analysis
  - CEV government provided hardware
  - Flight Test Execution
- **CLV**
  - Flight operations support to CLV including lead of First Stage Recovery System modification activities, Upper Stage RCS development and certification testing, and Abort Certification for all phases of CLV flight.
  - Support Separation Certification for all phases of CLV flight, CLV reliability and safety assessments including launch site function, CLV Mission Operations Planning to the Operations Integration organization, and Avionics Simulation development
- **Mission Operations**
  - **Project Management**
  - Development of capabilities and planning for mission operations, crew training, and the Mission Control Center for ESMD human space flight missions. Will be coordinated closely with SOMD as they will be responsible for operation of these vehicles.

KSC Task Distribution

- **Ground Operations**
  - **Project Management**
  - Responsible for achieving all Ground Operations objectives for the Agency allocated to the launch and landing sites.
  - Leads DDT&E and logistics activities for all ground processing, launch and recovery systems
  - Leads ground processing, launch and landing operations planning and execution
- **Crew Exploration Vehicle (CEV)**
  - Provides ground processing, launch operations and recovery support during DDTE phases of CEV
  - GSE development support
  - CEV prime contractor oversight and independent analysis
- **Crew Launch Vehicle (CLV)**
  - Provides ground processing, launch operations and recovery support during DDTE phases of CLV and CaLV
  - Performs prime contractor insight and independent analysis
  - Leads launch operations planning and execution for Advanced Development Test Flight (ADTF-0) and other flight demonstrations
- **Level II**
  - SR&QA - Support integrated hazards analysis and preliminary hazard analysis. Support Risk Management, quality assurance, and development of PRACA system. Represent SR&QA at assigned Systems Integration Groups (SIGs)
  - SE&I - Supportability Systems Integration Group (SIG) **co-lead** and Ground/Mission Ops **co-lead**
  - T&V - Support Integrated Element and end-to-end testing
  - APO - Support architecture refinement and conceptual design of future elements

LaRC Task Distribution

- **Crew Exploration Vehicle (CEV)**
  - **Lead** for Launch Abort System (LAS) Integration
    - CEV prime contractor oversight and independent analysis
  - Flight Test and Pathfinder Articles production for CM, LAS and separation rings
  - **Lead** the CM Landing System Advanced Development Project
  - Support the Thermal Protection System (TPS) Advanced Development Project
  - Aero/Aerothermal, GN&C, Avionics S/W, and Displays & Controls support
  - Independent Analysis and SE&I support
- **Crew Launch Vehicle (CLV)**
  - **Lead** Aerodynamic characterization of integrated launch vehicle stack, aerodynamic database development, and aeroelasticity test and analysis
  - **Lead** for vehicle integration activities for Advanced Development Flight Test-0 (ADFT-0)
  - **Lead** for CEV module development for ADFT-0
  - Support Structural design and analysis, Guidance, Navigation, and Control (GN&C) development, Flight Mechanics and trajectory analyses
  - Provide Systems Engineering support
  - Support Upper Stage DDT&E
- **Level II**
  - SR&QA - Support for integrated hazards analysis and probabilistic risk assessment; Represent SR&QA at assigned Systems Integration Groups (SIGs)
  - SE&I - Structures SIG **co-lead** and TPM **lead;** support to Requirements, Interface, Analysis & Trades and Process & Tools Offices; support to Software & Avionics, and Flight Performance SIGs
  - T&V - T&V Flight Test and Performance Planning; Support Integrated Loads, Structures & Mech, C3I T&V, Avionics SW T&V SIGS; and Flight Test Planning support
  - APO - Support architecture refinement and conceptual design of future elements

MSFC Task Distribution

- **Crew Launch Vehicle (CLV)/CaLV**
  - **Project Management for CLV and CaLV**
  - Responsible for achieving all CLV and CaLV objectives for the Agency.
  - Lead associated Systems Engineering & Integration activities, all CLV & CaLV S&MA activities, and Upper Stage DDT&E
  - First Stage design and Upper Stage Engine development contracts management, as well as leading or otherwise overseeing CLV associated demonstration testing.
  - Responsibility for ADFT-0 and other flight demonstrations
- **Crew Exploration Vehicle (CEV)**
  - Launch Abort Systems support
  - Service Module support
  - Abort Test Booster (ATB) requirements development and validation support
- **Level II**
  - PP&C - Support to the Management Systems Office (MSO), includes Deputy Lead for Level II MSO
  - SR&QA - Support integrated hazards analysis and probabilistic risk assessment; represent SR&QA at assigned Systems Integration Groups (SIGs); Support QA, risk management, and PRACA system development; Support Cx SR&QA panels.
  - SE&I - Thermal & ECLS SIG **co-lead**, Environments SIG **co-lead**, Human Factors/Human Rating SIG **co-lead**, Loads & Structures **co-lead**; IRD & SRD Book Manager; support to Requirements, Interface and Process & Tools Offices, support to Software & Avionics, Flight Performance, Power, C3I, Supportability SIGs
  - T&V - T&V **Lead** for Loads/Structures and Environments SIGs; Support to Flight Performance SIG, Human Factors & Human Rating SIG
  - APO - Support architecture refinement and conceptual design of future elements

SSC Task Distribution

- **Crew Launch Vehicle (CLV)**
  - Serve in a focused program **management and Integration** role for Constellation Systems rocket propulsion testing
  - **Lead** Sea Level Development, Certification & Acceptance Testing for Upper Stage Engine including facility modifications and test operations
  - Support Altitude Development & Certification Testing for Upper Stage Engine
  - **Lead** Sea Level Development Testing for Upper Stage Main Propulsion Test Article including facility modifications and test operations
  - **Lead** Sea Level Acceptance Testing for Flight Upper Stage Assembly including facility modifications and test operations
- **Ground Operations**
  - Support Design, Development, Test & Evaluation (DDT&E) of propellant test and delivery systems, ground engine checkout facility simulation and analysis, engine and launch facility planning and development
- **Level II**
  - SE&I - Support to Flight Performance Systems Integration Group(SIG) (propulsion test integration), and Systems Engineering Processes and Tools
  - T&V - Propulsion Test Integration and Coordination with Rocket Propulsion Test Management Board
  - APO - Support architecture refinement and conceptual design of future elements

Orion Loss of Crew Loss of Mission

Orion Loss of Crew and Loss of Mission Analysis

- As part of the Orion Integrated Design and Safety Analysis, Probabilistic Risk Assessment has played a very important role in increasing Vehicle safety and Mission Success.
  - To date, over 60 vehicle design changes have been implemented that improved LOC/LOM during five previous design cycles
    - OVEIWG Buy Back Round 1 (July 07 – Sept 07)
    - OVEIWG Buy Back Round 2 (Sept 07 – Nov 07)
    - DAC 2 LOC/LOM Improvements (Nov 07 – Oct 08)
    - Pre-DAC 3 LOM_T Risk Reduction (Oct 08 – Nov 08)
    - DAC 3 LOC/LOM Risk Reduction (Nov 08 – June 09)
  - Completing the detailed reliability analysis early in the design has provided significant benefits
    - Have considerably reduced Orion's LOC/LOM risk
    - Also improved Orion's capability to mitigate failures by identifying potential operational workarounds

Orion's Risk Informed Design Process

- Orion has employed a vigorous risk informed design process throughout the Project lifecycle
  - Probabilistic Risk Assessment (PRA) to estimate Loss of Crew (LOC)/Loss of Mission (LOM)
  - Hazard Analysis
  - Failure Mode Effects Analysis
  - Engineering and Operational judgment and analysis
- To date, over 60 vehicle design changes have been made to improve LOC/LOM during 5 design/analysis cycles
  - OVEIWG Buy Back Round1 (July 07 – Sept07)
    - Focused on LOC reduction
  - OVEIWG Buy Back Round 2 (Sept 07 – Nov 07)
    - Focused on LOM reduction
  - DAC 2 LOC/LOM Improvements (Nov 07 – Oct 08)
  - Pre-DAC 3 LOM_T Risk Reduction (Oct 08 – Nov 08)
    - Focused on LOM_T reduction
  - DAC 3 LOC/LOM Risk Reduction (Nov 08 – June 09)
    - Focused on reducing ISS LOC
- These design changes resulted in the following LOC/LOM improvements
  - ISS LOC: ~1/52 → 1/331
  - ISS LOM: ~1/3 → 1/60

Summary of Orion Risk Influenced Design changes (OVEIWG, DAC-2, DAC-3 Assessments)

- LRS: Redundant Forward Bay Cover Parachute, redundant NSIs for drogue chute mortars
- MMOD: Buy backs for LS LOC (Option 2A)
  - Add an MMOD shield to the Avionics Ring ALAS extension protecting the heatshield (+15 lbs).
  - Thicken the PICA in the region of the heatshield that is susceptible to impacts from MMOD coming through the SM/CM separation gap (+18 lbs).
  - Add 12 layers of Kevlar and associated separation foam and attachment hardware to the cylindrical regions of the main propulsion tanks (+140 lbs).
  - Add 4 layers of Kevlar and associated separation foam and attachment hardware to the forward dome regions of the main propulsion tanks (+51 lbs).
  - Add 6 layers of Kevlar and associated separation foam and attachment hardware to the aft dome regions of the main propulsion tanks (+104 lbs).
  - Add a 0.15” thick composite panel inner wall to the umbilical assembly (+16 lbs).
  - Maintain the two wall configuration of the LIDS Adapter (if present) (0 lbs).
  - Increase the CM RCS nozzle wall thickness to 0.187” from 0.045” (+136 lbs).
  - Thicken the backshell TPS substrate facesheets to 0.037” in windward regions and to 0.025” or 0.030” in the leeward regions (+205 lbs).
  - Thicken certain ½” prop lines in SM by approximately 0.010” (+2 lbs).
- Avionics/EPS: Addition of 2nd VMC, 2nd SCP, dual power feeds for VMCs & BFCS and ERM, data & power cross strapping, manual access to critical functions, Split Bus MBSU, addition of Ka-Band & S-Band HGA
- Avionics: 3rd VMC
- GNC: 3rd IMU, Addition of 2nd VPU and 2nd VNS external camera
- Prop: Addition of selected CM and SM RCS Isolation Valves, 1FT OME TVC
- Mechanisms: Redundant Solar Array Gimbals & Deployment motor windings
- Avionics: FCM, DCM and CCM functions & RIU PEC functionality separated into individual power zones, RIU network function cross-strapped, development of BEC
- ECLSS: O2 and N2 crossover valves added
- LRS: Incorporated Option-1 re-design (removed NSIs, mortars, pilot chutes, FBC deployable mains, etc.)
- ECLSS: Design (performance reasons) split ATCS from 2 to 4 loops (negative LOC/LOM impact), O_2 System updates for LOM/LOC risk reduction
- Avionics: Development of MRC, including 50% power mode (safe crew return)
- Prop: SM valve update for He Press LOM risk reduction, CM RCS Thruster Housing design for MMOD
- EPS: Forward work (ERB actions) to mitigate SM Battery LOM risk (unpowered SM Sep)
- ECLSS: ATCS Combined Heat Exchanger, PPO2 Sensor addition to CGA (non-vac CGA sensor), O2 & N2 Supply Regulators (series redundant in one leg), CM & SM ECLSS Drive Electronics (go forward with DAC-3 definition), CM Pump LOM Mitigation (cold spare pumps & controllers)
- Avionics: Ability for DCM Function Re-host to FCM, CM & SM RIU Dual Cmd/Pwr backplane
- Prop: SM He Pressurization change
- EPS: ISS Docked Power Down Using MRC, SPTU Option (revisit in DAC-3)
- MMOD: TPS Repair Capability, more SM Propulsion Line Protection
  - TPS (BS Repair): Current plan – NASA implement based on Shuttle experience
- TPS - switch to Avcoat main heat shield
- MMOD: 95% Tile Inspection effectiveness
- MMOD: Added ~73lbs. mass to vehicle for ISS DRM (Back shell tile thickness)

CxP Integrated Assessment Study
Summary Finding 4- External Contributing Factors

The study team identified several external factors that contributed to the inability of the CxP to meet its cost and schedule commitments. Among those factors were:

- An inadequate funding and reserve profile from the beginning of the program
- Unplanned budget challenges and continuing resolution restrictions
- Unfunded directed changes to design content
- Lateness in establishing a program leadership team and its relative inexperience in development
- Lack of early attention to systems engineering and integration
- Agency strategy to design CxP systems to meet both the near term earth orbit objectives and the longer term lunar objectives

Discussion of these and other external factors is outside the scope of this study, being addressed more fully in the “CxP Lessons Learned” briefing.

Ref: “Constellation Program INTEGRATED ASSESSMENT STUDY”, Lee Norbraten, CxP Review Manager, January 28, 2011, slide 11.